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Nonlinear compression of mJ-level pulses via double-pass loose focusing in air

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Developing high-intensity lasers with ultrashort pulses is crucial for strong field physics and its applications [1]. Simultaneously amplifying ultrashort pulses and shortening pulse duration represent a great challenge. The most prevailing ultrashort high-power lasers are titanium:sapphire (Ti:Sa) and ytterbium (Yb) ion-doped lasers. Compared to extremely broadband Ti:Sa lasers, lasers using Yb-doped gain media are found to have better average power scalability but a narrower emission bandwidth. There are commonly two methods employed to achieve high peak and average power of femtosecond sources: optical parametric amplification (OPA) and post-compression. OPA offers a method to amplify a supercontinuum pulse over a large bandwidth by pumping it with narrow-band but high-energy laser pulses. Post-compression methods directly broaden the spectral width of the high-power pulses through nonlinear interactions such as self-phase-modulation [2].

The post-compression approach is attractive for power-scaling applications due to the low losses. Various efficient post-compression methods have been demonstrated for millijoule-level pulses, including hollow-core fibers [3], multiple plates [4], and multi-pass cells (MPC) [2]. Hollow-core fibers allow for smaller beam diameters than capillaries and are filled with noble gases as the nonlinear medium. In this scheme, the beam pointing and pulse energy should be precisely controlled not to damage the fibers. Multi-plate setups are compact but require accurate design for specific pulse parameters, and readily lead to self-focusing and beam quality degradation. The MPC based on the Herriott cavity offers high-energy handling and good beam quality, yet the alignment becomes sensitive when the spot sizes modified by Kerr lenses should be taken into account during mode-matching.

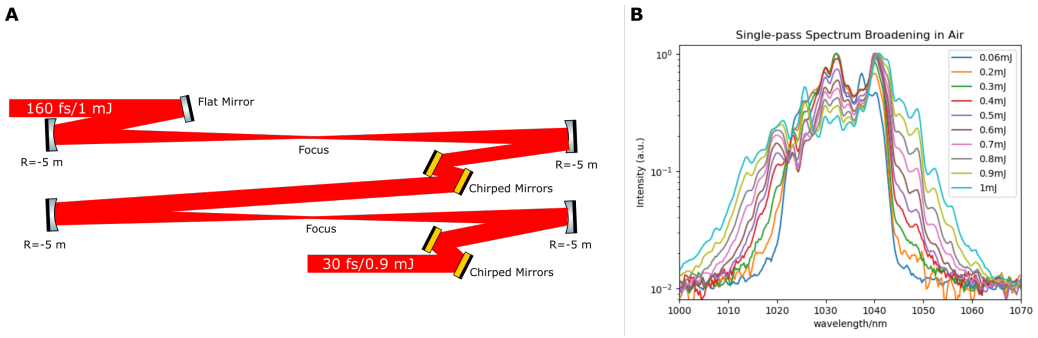

Fig. 1 (A) Two-pass pulse post-compression setup. (B) Spectral broadening after a single pass with different input pulse energy

Here we report on a novel two-pass-based scheme for nonlinear pulse compression in the 200 uJ to 1 mJ pulse energy range, which overcomes the pulse energy limitation and beam quality degradation, and features extreme simplicity, high compression efficiency, and average power scaling capabilities. Instead of coupling to a solid nonlinear medium or aligning to an optical cavity in the vacuum, laser pulses are loosely focused in air to induce nonlinear broadening with limited self-focusing, combined with chirped-mirror-based compression between passes, as shown in Fig. 1A. This approach is inspired by the CASCADE concept [5]. The single pass through the Kerr medium, air, corresponds to a B-integral $\approx 0.6\pi$ by using a 1 mJ pulse at 1030 nm center wavelength and substantial spectral broadening can be achieved, as shown in Fig.1B. In our design, we expect that mJ-level pulses can be compressed from 160 to 30 fs in FWHM after two-pass propagation. The output stability also benefits from little or no self-focusing during the broadening. Our work provides a cost-efficient and simple pulse compression method, and gives a set of guidelines on how to implement such a post-compression setup.

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